Decision Criteria
for the
Reusable Launch Vehicle Technology Program
Phases II and III

Comments developed jointly with OMB, OSTP, and NASA staff

Executive Summary

This report documents the criteria which will provide the basis for decisions in 1996 and the end of the decade on whether or not to proceed with Phase II (X-33 Advanced Technology Demonstrator) and Phase III (Commercial Development of a Next-Generation Space Launch System) of the NASA Reusable Launch Vehicle (RLV) program, consistent with the National Space Transportation Policy. The criteria contained in this document are established in accordance with the 11-point agreement between NASA and OMB signed by NASA Administrator Daniel S. Goldin on November 25, 1994. The criteria are subject to change by consensus agreement of OMB, OSTP, and the NASA Administrator and will be reviewed by the NASA Advisory Council or other equivalently qualified panel. Furthermore, the NASA Administrator will report annually to OMB/OSTP on the progress of the program toward meeting the decision criteria. It is also the intent for RLV partners to review and suggest updates to the criteria as configuration studies, vehicle designs, and technologies mature.

The Reusable Launch Vehicle Technology Program is currently in Phase I. Funding has been identified in the President's FY 1996 Budget which will enable a White House decision in 1996 on whether or not to proceed with Phase II. Phase II will include development and testing of the Advanced Technology Demonstrator (ATD), designated the X-33 by NASA, flight testing of the X-34 experimental vehicle and a complimentary ground test program. The 1996 decision is contingent upon programmatic and technical criteria, all of which are supported by numerous specific, technical metrics at the project and task level during Phase I. Included in the programmatic criteria for the Phase II decisions are the DC-XA and X-34 programs which support the concept that small, industry-led Government/industry project teams are an efficient management tool for the rapid prototyping of advanced space launch technology. During Phase I, the X-34 program must demonstrate progress toward the timely fielding of a commercially viable space launch system which significantly reduces the price of launch in its payload class.

The objective of Phase II will be to demonstrate the ability to significantly reduce the cost of development, production, and operation of future, new-launch vehicle systems. Traditional cost estimating techniques will be applied to selected X-33 and X-34 designs and compared against established funding levels to determine the magnitude of expected development and production savings. This document will be updated to reflect those cost reduction goals. Operations cost reductions will be demonstrated by the use of small ground crews and successful flight demonstrations of the DC-XA, X-34, and X-33.

The Phase III decision is dependent upon business and operations plans, specific technical metrics, and programmatic criteria. Included in the technical criteria is the X-33 demonstration,

(focused on rocket-based single-stage-to-orbit feasibility) that low-cost access to space is technically feasible and that development, production, and operational costs for such a vehicle are acceptable. The two pacing programmatic requirements are (1) the X-33 and X-34 programs have demonstrated that cooperative Government/industry technology development programs can be both successful and efficient, and (2) acceptable business arrangements have been reached between Government and industry that will facilitate the development and operation of the next generation of space launch systems. A decision to enter Phase III would end the RLV technology program and begin full-scale development. It is envisioned that the timing of this decision will coincide with investment decisions on the Space Shuttle program required to maintain its capability through 2012. Department of Defense progress in the Evolved Expendable Launch Vehicle program, the evolution of commercial markets, budget limitations and national needs will also be considered.

RLV Technology Program Criteria

The RLV design and operations target requirements provided in this document do not represent independent pass/fail criteria and should be assessed in the context of an overall systems analysis. Achievement of the required advancement in each area will be assessed with respect to its effect on the total system's ability to perform its mission with acceptable design, development, and operational risks. As with all technology programs, interim decisions will be required as part of the overall systems engineering effort and are identified in this document where appropriate.

RLV Technology Program Phase II Decision Criteria

The decision to enter Phase II is predicated on meeting programmatic (preliminary business and operations planning) and technical criteria. These criteria are based on those goals of the RLV technology program which will be completed prior to the 1996 decision. In addition to these criteria, the Government will assess the impact of outyear funding instability and technical and programmatic risk.

Phase II Programmatic Criteria

Significant reductions in development and operations costs will require streamlining of management methods used to oversee the technology development and demonstration efforts. The following programmatic criteria will be the basis for demonstrating the "new ways of doing business" required to reduce development and operations costs of a next-generation reusable launch system.

1. Preliminary business plans for next-generation system development, production and operation (Phases II and III) will be completed. These plans will be created by the industry partners as a product of the Government-industry partnership and will contain detailed cost and business investment strategies, schedules and decision milestones for proposed Phase II activities. The business plans will also contain detailed operating plans which identify specific technology improvements to be demonstrated consistent with cost targets. Other specific components of this plan include:

- Cost/benefit assumptions which include cash, debt, discounting, revenue stream, depreciation, interest and taxation options.
- Financial investment sources and requirements. Requirements discussion will include Government policy changes which would be required to obtain private financing (e.g., termination liability, anchor tenancy) and legislation or policy required to permit other unique Government-industry partnerships.
- Cost and schedule estimates to develop, manufacture, activate, and operate all ground, flight and related support systems. These estimates should project significant reductions in cost

from other traditional launch vehicle developments and must be comprehensive to a level that will permit credible, independent assessments.
- Planned and required return on investment for 10-year projections.
- Identification of risks and mitigation plans.
- Management and acquisition mechanisms which will result in significant cost reduction from traditional Government-led programs.
- Identification of commercial payload insurance plans.

If Phase II is initiated, this plan will be updated prior to the Phase II decision.

2. The use of small and efficient project offices is critical to demonstrating low-cost development capabilities, streamlined acquisition strategies, minimal Government oversight, and other cultural changes required to meet the cost reduction goals of the RLV technology program. This will be demonstrated with the following criteria.

a. The RLV Technology Program Management Office, including the X-33, X-34, DC-XA, and dedicated technology management offices, will be maintained at a level no larger than 20 people (12 at the Marshall Space Flight Center and 8 at NASA Headquarters). The intent is to demonstrate streamlined management techniques required to reduce cost.

b. The DC-XA program must demonstrate that a small and efficient Government/industry project team can design, develop, and integrate advanced technology components (including cryogenic tankage and primary structure) into an experimental flight system within budget. The total touch labor ground crew associated with the DC-XA will be no larger than the 15 people used on DC-X. DC-XA flight operations will be performed with no more than three personnel (same as DC-X). Achievement of initial flight testing is not required for this criterion to be satisfied.

c. Traditional cost estimating methods applied to the X-34 program have shown that development and production of a similar vehicle could range from $250-500 million. It is the intent of the X-34 program to demonstrate a significant reduction in these costs by incorporating innovative design methods, streamlined acquisitions, and other new ways of doing business in an industry-led format. Government funding for the X-34 will be limited to $70 million with remaining funds to be provided by industry. Once the X-34 partner has been selected, traditional development and fabrication cost estimates will be calculated for the selected configuration to establish a baseline for future comparisons. The negotiated contract value for the X-34

program is expected to be 25 to 50 percent below this baseline.

Prior to the Phase II decision, the X-34 program will have a negotiated contract reflecting an industry cost share greater than 50 percent of the total budget (i.e., the contractor must meet this requirement on a fiscal year and cumulative basis). In addition, the X-34 program must achieve its development goals and do so on schedule and ~~on~~ within a fixed Government budget. Design freeze of the X-34 will have been completed prior to the Phase II decision.

3. The initial design review and two nonadvocacy reviews of the X-33 program will have been completed and documented.

4. The X-33 selection will have been completed.

Phase II Technical Criteria

It is the Government's belief that the most promising means for low-cost access to space are highly reusable and robust launch vehicles. A full reusable, single-stage-to-orbit configuration may offer the lowest possible cost and is the target of initial RLV technology efforts. Prior to beginning Phase II (1996), critical technologies that would be required to demonstrate the concept of low-cost (development, production, and operations) reusable systems will be demonstrated through small-scale experimental testing. Analytical results derived from these demonstrations will be used to determine whether an advanced technology demonstrator can be fabricated and whether or not it is likely to adequately demonstrate the technical feasibility and cost advantages of single-stage-to-orbit.

Careful consideration has been given to the selection of the criteria technologies with an insistence that results would have direct application to other reusable multistage systems. The four key technology areas are (1) reusable cryogenic tank systems, (2) primary vehicle structures, (3) thermal protection systems, and (4) propulsion. Other technology areas such as avionics and flight software will be incorporated into the DC-XA and X-34 vehicles for demonstration and/or qualification but are not a primary focus of the ground test program. Criteria for each of the key technology areas are provided below and will be used to measure the progress and performance of these technologies.

Note: This document will be reviewed by the industry teams and criteria may be updated to reflect changes in the technology program.

1. <u>Reusable Cryogenic Tank Systems (RCTS)</u>. There are currently no RCTS suitable for use in launch vehicles. Technology development efforts during Phase I will demonstrate the relative

merits of composite and metallic materials for RCTS application in the X-33 and potential RLV configurations. Final material selection for the X-33 design will be based on systems analyses which incorporate the technology program results.

The primary issue being addressed by this technology area is the lack of data available to evaluate material property, life cycle, manufacturing, inspectability and repairability of potential tank materials as applied to reusable cryogenic tanks. Therefore, the objective of RCTS technology efforts is to determine whether or not they can be functionally produced and whether weight, reuse, cost and operations requirements for X-33 and RLV configurations can be met. At the time of the Phase II decision, data from this technology effort will be used to determine whether or not reusable cryogenic tanks can be integrated into an X-33 flight test vehicle to support the demonstration of single-stage-to-orbit by the end of the decade.

a. At least one metallic (aluminum-lithium) tank will be constructed and integrated with the required TPS, health monitoring, and attachment subsystems and will be under test. Current plans call for two such tanks to be manufactured and integrated for test. Appropriate coupon and other element testing (e.g., LOX compatibility, reusability) required to achieve this goal will be completed and documented. All applicable subscale testing will have been conducted to scaled (to full-scale RLV) pressures and loads.

b. At least one graphite composite tank will be constructed and integrated with the required TPS, health monitoring, and attachment subsystems and will be under test. Current plans call for two such tanks to be manufactured and integrated for test. Appropriate coupon and other subscale testing (e.g., LOX compatibility) to achieve this goal will be completed and documented.

c. The material selection for both fuel and oxidizer tank subsystems will be completed and documented. The selection must consider performance (e.g., weight, strength) producibility, inspectibility, and operability characteristics.

d. A documented analysis will have been completed which demonstrates that the selected materials and tank subsystems are scaleable to a full-scale RLV and will adequately be demonstrated by an X-33 vehicle. This analysis will contain the correlations between analytical predictions and experimental test results. These correlations will be at a level of confidence sufficient to ensure that analytical tools are valid for purposes of full-scale vehicle design. Estimated requirements for the RLV, which will be supported by this analysis, are a

minimum of 100 lifetime missions including depot maintenance no more than every 20 missions, volumetric weight targets (which will be updated for selected X-33 configuration) of 0.7 pounds per cubic foot or less for a oxidizer tank and 0.5 pounds per cubic foot or less for a liquid hydrogen tank, and leakage rates within the limits set for the Space Shuttle.

2. Primary Vehicle Structures (PVS). Criteria under this section will be used to measure the progress and validate the feasibility of composite structure applications to launch vehicle environments. Technology development efforts during Phase I will demonstrate relative merits of state-of-the-art composite materials for application in PVS (e.g., wing or aero-surface, intertank, thrust structure) subsystems for the X-33 and potential RLV configurations. Final material selection for the X-33 design will be based on systems analyses which incorporate the technology program results.

The primary issue being addressed by this technology area is the lack of data available for estimating the material property, life cycle, manufacturing, inspectability and repairability of potential composite materials as applied to primary structures in launch vehicle environments. Therefore, the objective of the PVS technology effort is to determine whether or not they can be produced to meet weight (primary structure materials have the largest system weight impact), reuse, cost and operations requirements for X-33 and RLV configurations. Information from the technology efforts, described by the following criteria, will be used to determine whether or not reusable PVS can be built and integrated into an X-33 flight test vehicle to support the demonstration of single-stage-to-orbit by the end of the decade.

a. At least one composite intertank test article will be constructed and integrated with the required TPS, health monitoring, and attachment subsystems and will be under test. Appropriate coupon and other subscale testing (e.g., pull-test, panel specimen) required to achieve this goal will be completed and documented.

b. At least one composite thrust structure test article will be constructed and integrated with the required, health monitoring, and attachment subsystems and will be under test. Appropriate coupon and other subscale testing (e.g., pull-test, panel specimen) to achieve this goal will be completed and documented.

c. At least one composite wing or aero-surface test article will be constructed and integrated with the required TPS, health monitoring, and attachment subsystems and will be under test. Appropriate coupon and other subscale testing

(e.g., pull-test, panel specimen) to achieve this goal will be completed and documented.

d. The material selection for intertank, thrust structure, and wing or aero-surface will be completed and documented. The selection must consider performance (e.g., weight, strength) producibility, inspectibility, and operability characteristics.

e. A documented analysis will have been completed which demonstrates that the selected materials and primary structure subsystems are scaleable to a full-scale RLV and will adequately be demonstrated by a X-33 vehicle. This analysis will contain the correlations between analytical predictions and experimental test results. These correlations will be at a level of confidence sufficient to ensure that analytical tools are valid for purposes of full-scale vehicle design. Estimated requirements for the RLV, which will be supported by this analysis, include a weight target of 4.0 pounds per square foot of surface area or less for the airframe structure (TPS, VHM not included).

3. Thermal Protection Systems (TPS). Criteria under this section will be used to measure the progress and validate the feasibility of thermal protection system materials as applied to anticipated launch vehicle environments. Specific emphasis will be placed on the operability characteristics of TPS options. Technology development efforts during Phase I will demonstrate relative merits of existing TPS materials for application in integrated primary structure and reusable cryogenic tanks for the X-33 and potential RLV configurations. Final material selection for the X-33 design will be based on systems analyses which incorporate the technology program results.

The primary issue being addressed by this technology area is the lack of data available to estimate the durability and reuse of potential TPS materials in launch vehicle environments. Therefore, the objective of this technology effort is to determine whether or not they can be produced and integrated to meet weight, reuse, cost and operations requirements for X-33 and RLV configurations. Information from the technology efforts, described by the following criteria, will be used to determine whether or not reusable and operationally efficient TPS components can be built and integrated into an X-33 flight test vehicle to support the demonstration of single-stage-to-orbit by the end of the decade. Materials and attachment options will be investigated. Integration of TPS options onto structural test articles is addressed in the reusable cryogenic tank and primary structure technology areas.

a. At least one ceramic TPS test article will be constructed and under test. All appropriate element testing required to

achieve this goal will be completed and documented. Appropriate attachment mechanisms will have been analyzed and preferred technologies included in the test article.

b. At least one metallic TPS test article will be constructed and will be under test. All appropriate element testing required to achieve this goal will be completed and documented. All appropriate attachment mechanisms will have been analyzed and preferred technologies included in the test article.

c. Material selection for TPS applications in primary structure and reusable cryogenic tank sections will be completed and documented. The selection must consider performance (e.g., weight, durability) producibility, inspectibility, and operability and cost characteristics.

d. A documented analysis will have been completed which demonstrates that the selected materials and TPS subsystems are scaleable to an operational RLV and will adequately be demonstrated by a X-33 vehicle. This analysis will contain the correlations between analytical predictions and experimental test results. These correlations will be at a level of confidence sufficient to ensure that analytical tools are valid for purposes of full-scale vehicle design. Estimated requirements for the RLV, which will be supported by this analysis, include a 100-mission minimum lifetime, and an order of magnitude reduction in maintenance and inspection requirements as compared to existing Shuttle TPS (a baseline for Shuttle will be developed for inclusion in this criteria).

4. Propulsion Systems. Criteria under this section will be used to measure the progress of propulsion system options in meeting reuse and operations requirements of an RLV. Technology development efforts during Phase I will demonstrate relative merits of existing propulsion systems for the X-33 and potential RLV configurations.

The primary issue being addressed by this technology area is the lack of data available to evaluate the performance, operability, inspectibility and reuse of potential RLV propulsion systems. The objective of this technology effort is to determine the preferred propulsion system for meeting reuse, cost, and operations requirements of X-33 and RLV configurations.

a. The propulsion technology area will be adjusted by August 1995 to reflect the needs of the X-33 industry partners. Propulsion systems not required by the proposed X-33 or RLV systems will not be funded by this program.

b. A propulsion concept will be selected prior to the Phase II decision which will be required by the preferred RLV configuration.

c. A documented analysis will have been completed which demonstrates that the selected propulsion subsystems are scaleable to a full-scale RLV and reuse/operations requirements will be adequately demonstrated by a X-33 vehicle. Estimated requirements for the RLV, which will be supported by this analysis, include a 100-mission life with 20 flights between depot maintenance and a 50 percent reduction in engine inspection time between flights as compared to the Shuttle.

d. Results from component work will be documented and provided with the above analysis. Only propulsion technology supporting the X-33 contractors will be pursued within this program.

Phase III Decision Criteria

RLV Technology Program Phase III Decision Criteria

The decision to enter Phase III signifies the end of the RLV technology program and the beginning of a potential RLV full-scale development. It is envisioned that the timing of this decision (at end of the decade) will coincide with investment decisions on the Space Shuttle program required to maintain its capability through 2012. Department of Defense progress in the Evolved Expendable Launch Vehicle (EELV) program, the evolution of commercial markets, budget limitations and national needs will also be considered in the RLV development decision. The following criteria will be used to measure the progress and performance of the RLV technology program will be the basis of Government and private-sector decisions on development of an operational next-generation reusable launch system.

1. Acceptable business arrangements will have been developed between Government and industry to permit development of a low-cost next-generation space launch system.

2. The X-33 and X-34 programs will have demonstrated, by meeting their respective program goals within a fixed Government budget, that the industry-led, cofunded development of advanced space launch technology is an efficient, cost-saving program implementation approach. Specific objectives are listed below.

   X-34 Criteria

   a. The NASA/industry team will have demonstrated a reduction in development and production costs of 25 to 50 percent relative to the traditional cost estimate established in

Phase II by developing a small reusable or partially reusable booster.

b. The NASA/industry team will have demonstrated a factor of approximately three reductions in launch costs as compared to existing vehicles in the same payload range by developing a small reusable or partially reusable booster.

c. The NASA/industry team will have demonstrated with a small reusable, or partially reusable booster technologies scaleable to potential RLV configurations which include the following:

   - As a part of the basic booster design, the demonstrated technologies will have included reusable composite or metallic tanks, reusable and operable engines, reusable and durable TPS materials, operations concepts.

d. The NASA/industry team will have demonstrated reusability and operability concepts which significantly reduce launch costs and demonstrate rapid processing for reflight by developing a small reusable or partially reusable booster. The present target is to demonstrate operability concepts which result in 0.5 hours of labor per pound of structure per flight. For comparison, current launch systems average approximately 10 hours per pound of structure per flight, varying by vehicle type and size.

e. The X-34 will have initiated flight tests by March 1998.

f. The X-34 will have demonstrated orbital delivery capability by December 1998.

g. The X-34 vehicle will have provided flight data to support validation of vehicle hypersonic flight environments during ascent and reentry.

h. The NASA/industry team will have demonstrated through their innovative partnership, a successful development within 3 years and with a fixed-Government funding profile.

X-33 Criteria

a. The NASA/industry team will have developed and demonstrated with an advanced technology demonstrator a potential reduction in development and production costs of 25 to 50 percent. (The specific percentage goal will be determined once the final configuration is selected. The comparison will be made between traditional cost estimating methods and X-33 funding to determine the goal.)

b. The NASA/industry team will have demonstrated with an advanced technology demonstrator technologies scaleable to potential RLV configurations which include the following:

   - As a part of the basic booster design, the demonstrated technologies will have included reusable composite or metallic tanks and primary structure, reusable and durable TPS materials, and operations concepts.

c. The NASA/industry team will have developed and demonstrated with an advanced technology demonstrator reusability and operability concepts which when applied to the RLV will significantly reduce launch costs and demonstrate rapid processing for reflight. The present operational RLV goal is to demonstrate operability concepts which result in 0.5 hours of labor per pound of structure per flight. For comparison, current launch systems average approximately 10 hours per pound of structure per flight, varying by vehicle type and size.

d. The X-33 will have initiated flight tests by March 1, 1999.

e. The X-33 will have flown at least two missions by the Phase III decision with no more than 50 touch-labor ground personnel. Concepts will have been demonstrated which support a 2-week reprocessing for flight.

f. The X-33 vehicle will have provided flight data to support validation of vehicle hypersonic flight environments during ascent and reentry.

3. A transition plan for the Space Shuttle will have been developed. This transition plan will detail the estimated costs associated with maintaining the Shuttle to 2012 and beyond. A comparison of cost estimates for candidate RLV configurations and a mission requirements analysis (e.g., mission model) will also be included.